

Dark Matter Searches with H.E.S.S.

Knut Dundas Morå on behalf of the H.E.S.S. collaboration
Stockholms universitet
Kosmologi astropartikelfysik och strängteori
106 91 Stockholm

Cosmological measurements indicate that a large component of non-visible gravitating matter is present in the universe. A common hypothesis for its origin is a weakly interacting, massive particle. Annihilations or decays of such particles could produce gamma rays. The H.E.S.S. experiment is an imaging air Cherenkov telescope array located in Namibia which may detect very high energy gamma-rays between 300 GeV and 10 TeV. This talk will present an overview of two recent H.E.S.S. searches for dark matter in the very high energy region, one targeting dwarf galaxies, the other one a cored dark matter profile at the galactic center.

1 Introduction

Measurements of gravitational wells of galaxies and galaxy clusters cannot be explained by baryonic matter alone. Dark matter that (almost) exclusively interacts through gravitational interactions, would explain both these and cosmological observations well. Planck finds that the amount of dark matter is roughly 5 times that of baryonic matter¹. If the dark matter is made up of particles that have weak interactions, they may be thermally produced in the early universe with the observed abundance. For this reason, weakly interacting massive particles (WIMPs) are a widely studied dark matter candidate. Two WIMPs may annihilate into standard model particles, which could lead to an observable signal in gamma rays.

The High Energy Stereoscopic System (H.E.S.S.) is an array of four 12-meter and one 28-meter imaging Cherenkov telescopes located in the Namibian Khomas Highland. In the two following analyses, only H.E.S.S. phase one data (four 12-meter telescopes) has been studied. High-energy cosmic rays and photons create showers in the atmosphere that emit Cherenkov light, which may be observed by fast cameras on the telescopes. Details on the H.E.S.S. experiments may be found in². For typical analyses, the fiducial field of view is 2° in diameter, and the effective area is $\sim 1 \times 10^5 \text{ m}^2$ above 400 GeV. Under favorable conditions the analyses with H.E.S.S. I may be performed down to approximately 300 GeV.

This proceeding will summarize dark matter searches published by the H.E.S.S. collaboration the last year, one targeting Dwarf Spheroidal Galaxies, the other the Galactic center.

2 Search for Dark Matter in Dwarf Spheroidal Galaxies

Dwarf Spheroidal Galaxies, dSphs, are satellites of the Milky Way. Inferred mass-to-light ratios up to several hundred from stellar velocity measurements indicate that they are some of the most dark matter dominated systems in the universe. Astrophysical backgrounds that might emit gamma rays are also low, making dSphs promising targets for indirect dark matter searches. The H.E.S.S. experiment has searched for dark matter signals from five dSphs, with a total

exposure of 140 hours ³ taken between 2006 and 2012. This is a fivefold increase with respect to the previous search with dSphs published by H.E.S.S ⁴. The Sagittarius dSph is the nearest of the five at 25 kpc, and was observed for 90 h. The Coma Bernices, Fornax, Carina and Sculptor dSphs were observed with between 6 and 12.7 h each.

A circular signal region of $\theta \leq 0.1^\circ$ is chosen from the instrument point spread function ². Background regions are constructed as a ring centered on the observation position ^a. Reconstruction of events, as well as gamma-hadron separation is done using the *faint* selection of the X_{eff} analysis ⁵.

In order to compute limits on the dark matter cross section, the integrated dark matter content along the line-of-sight l , called the J-factor is needed:

$$J = \frac{1}{\Delta\Omega} \int_l \int_{\Delta\Omega} \rho_{\text{DM}}^2 dl d\Omega \quad (1)$$

In this analysis, J-factors and attendant uncertainties were using a novel Bayesian two-level likelihood that exploits that dark matter parameters are shared by all dSphs to infer the dark matter content of individual dSphs. Details are found in ⁶.

The energy spectrum of the dark matter annihilation signal depends on what standard model particles take part. An annihilation to two photons leads to a striking line feature, but this is usually loop-suppressed in comparison with annihilations to leptons or quarks. In this analysis, the expected gamma ray spectra for annihilation into vector bosons, $b\bar{b}$ and leptons from ⁷ are assumed. A binned likelihood in energy for both OFF and ON spectra utilized the spectral information to improve the sensitivity.

No significant excess is observed between signal and background region for any of the five dSphs. The significances for point sources across the fields of view are consistent with the background only hypothesis. Combined limits for all five dwarfs are set using the profile likelihood procedure, and are shown in figure 1. The J-factor is included as a nuisance parameter, including the estimated errors. The combined limit reaches $\langle\sigma v\rangle \approx 1.4 \times 10^{-23} \text{ cm}^3 \text{ s}^{-1}$ for annihilation into vector bosons. In the case of annihilation to $\mu^+\mu^-$ or $\tau^+\tau^-$ limits improve, although not enough to reach a scan of supersymmetric models.

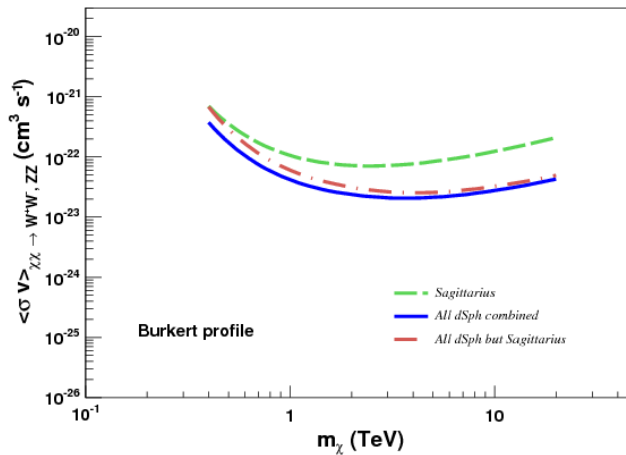


Figure 1 – Limits on the dark matter self-annihilation cross section from five dwarf galaxies for annihilation into vector bosons.

3 Search for Dark Matter from a Cored distribution in the Galactic Center

Another search has been published using the Galactic center as the target ⁸. N-body simulations of dark matter halos find that the density is sharply cusped, see fig. 2. Previous analyses done

^a see ²

with H.E.S.S. have searched for cusped profiles^{9 10}. However interactions with baryonic matter could lead to a situation where the dark matter density is constant in the center of the galaxy¹¹. Most observations done with H.E.S.S. use background and signal regions contained within the same $2^\circ \approx 300$ pc field of view. A dark matter core could lead to roughly the same dark matter content in signal and background regions, reducing the sensitivity. Therefore, this analysis uses separate background pointings, leading to the strongest limits on dark matter annihilation without assuming a dark matter cusp. Limits are provided for the case of a core radius of 500 pc, but can be translated to core radii up to 2 kpc.

In order to obtain OFF-regions outside a 500 pc core, dedicated telescope pointings were done leading to the signal and background coverage shown in figure 2. Each observation of the ON-region was preceded and followed by an OFF-run, equalizing the region of the atmosphere covered in each of the three runs. A total of 9 h of data were taken, 3 h on the signal region.

Events are selected and reconstructed as described in². A cut in galactic latitude $|b| < 0.3^\circ$ is imposed to exclude astrophysical backgrounds in the Galactic plane. After this cut, as well as image cleaning cuts, no excess is seen in sky maps of the signal or background positions. The total excess of the signal region, including a 2% uncertainty on the exposure ratio has a statistical significance of -0.5σ . As no significant signal is observed, upper limits on the velocity averaged dark matter annihilation cross section are derived. Figure 3 shows limits as function of dark matter mass. Cross sections above $\langle \sigma v \rangle \approx 3 \times 10^{-24} \text{ cm}^3 \text{ s}^{-1}$ are excluded in the mass region of highest sensitivity, between 1 and 4 TeV, for a dark matter density profile featuring a 500 pc core. If a cusped profile is assumed instead, the limits derived in this analysis improve by roughly a factor of 2.

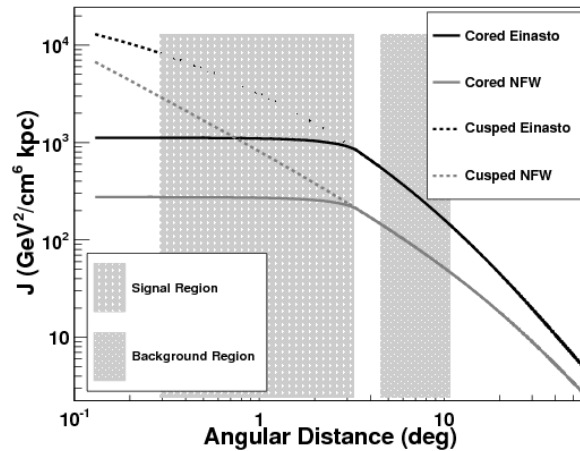


Figure 2 – J-factors of the galactic center for cored and cusped dark matter profiles are displayed. The gray bands show the ON and OFF regions.

4 Summary and Outlook

The H.E.S.S. experiment has set limits on the annihilation of dark matter particles from the Galactic center and selected dwarf galaxies. For the Galactic center, a dedicated pointing strategy let the experiment set the strongest current limit on the annihilation of TeV-scale dark matter particles without the assumption of a cusped profile. H.E.S.S.-II adds a single 28 m telescope to the array. The larger dish area lowers the energy threshold of the array, and will allow H.E.S.S.-II to bridge the gap between previous searches and Fermi-LAT. The first results of H.E.S.S.-II are being published, including preliminary work on updated dark matter searches^{12 13}.

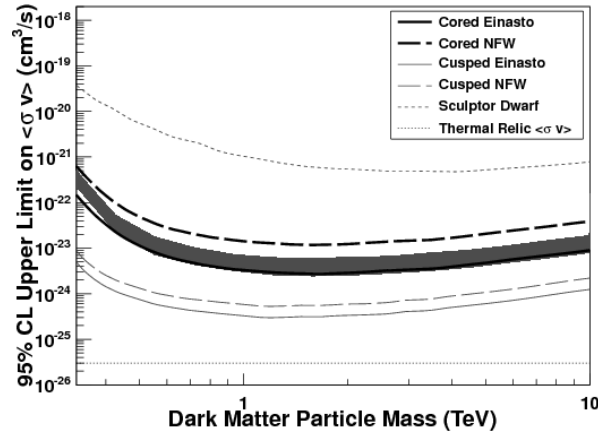


Figure 3 – Upper limits on the annihilation cross-section of dark matter from the galactic center.

References

1. P. A. R. Ade et al. (Planck Collaboration). Planck 2015 results. XIII. Cosmological parameters. 2015.
2. F. Aharonian et al. (H.E.S.S. Collaboration). Observations of the Crab nebula with H.E.S.S. *A&A*, 457(3):899–915, 2006.
3. A. Abramowski et al. (H.E.S.S. Collaboration). Search for dark matter annihilation signatures in H.E.S.S. observations of Dwarf Spheroidal Galaxies. *Phys. Rev.*, D90:112012, 2014.
4. A. Abramowski et al. (H.E.S.S. Collaboration). H.E.S.S. constraints on dark matter annihilations towards the Sculptor and Carina dwarf galaxies. *Astropart. Phys.*, 34:608–616, March 2011.
5. F. Dubois et al. A multivariate analysis approach for the imaging atmospheric Cherenkov telescopes system H.E.S.S. *Astropart. Phys.*, 32:73–88, 2009.
6. G. D. Martinez. A robust determination of Milky Way satellite properties using hierarchical mass modelling. *MNRAS*, 451:2524–2535, August 2015.
7. J. A. R. Cembranos et al. Photon spectra from WIMP annihilation. *Phys. Rev.*, D83:083507, 2011.
8. A. Abramowski et al. (H.E.S.S. Collaboration). Constraints on an Annihilation Signal from a Core of Constant Dark Matter Density around the Milky Way Center with H.E.S.S. *Phys. Rev. Lett.*, 114(8):081301, 2015.
9. A. Abramowski et al. (H.E.S.S. Collaboration). Search for a Dark Matter Annihilation Signal from the Galactic Center Halo with H.E.S.S. *Phys. Rev. Lett.*, 106(16):161301, April 2011.
10. A. Abramowski et al. (H.E.S.S. Collaboration). Search for Photon-Lineline Signatures from Dark Matter Annihilations with H.E.S.S. *Phys. Rev. Lett.*, 110:041301, 2013.
11. A. Pontzen and F. Governato. Cold dark matter heats up. *Nature*, 506:171–178, 2014.
12. M. Kieffer et al. for the H.E.S.S. Collaboration. Search for Gamma-ray Line Signatures with H.E.S.S. In *Proceedings, 34th International Cosmic Ray Conference (ICRC 2015)*, 2015.
13. V. Lefranc and E. Moulin for the H.E.S.S. Collaboration. Dark matter search in the inner Galactic halo with H.E.S.S. I and H.E.S.S. II. In *Proceedings, 34th International Cosmic Ray Conference (ICRC 2015)*, 2015.